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TESTS OF SIX TYPES OF BAKELITE-BONDED WIRE STRAIN GAGES

By William R. Campbell

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TESTS OF SIX TYPES OF BAKELITE-BONDED WIRE STRAIN GAGES

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SUMMARY

Results of tests are given for 10 gages of each of 6 types of multi-strand, single-element, bakelite-bonded wire strain gages. The calibration factors for the 10 gages of a given type differed from the average factor for that type by not more than ±1.6 percent. For one of the six types this difference was less than ±0.4 percent.

284°F

Two of the six types of gages showed no reduction in calibration factor at temperatures up to 140° C. Four types of gages showed a reduction in calibration factor at 140° C which ranged from 3 to 9 percent. The reduction in calibration factor became noticeable for all types of gages at a temperature of 170° C. 338°F

Creep was measured on one pair of gages of one type at constant strain. The gages showed no creep at temperatures as high as 140° C. At 170° C the creep at the end of 1 hour amounted to 6 percent of the applied strain.

The maximum difference in unit change in gage resistance between different gages of the same type when attached to unstressed steel bars and subjected to changing temperature did not exceed 0.02×10^{-4} per degree centigrade for advance gages and 0.15×10^{-4} per degree centigrade for isoelastic gages.

Gage resistance was found to vary almost linearly with the power dissipated by a gage. The unit change in gage resistance per watt of power dissipated by the gage ranged from -10.8×10^{-4} for advance gages to 190×10^{-4} for isoelastic gages.

INTRODUCTION

The purpose of the tests was to determine important performance characteristics for several types of bakelite-bonded wire strain gages which are representative of gages in current use by the aircraft industry. Six types of commercially available gages were selected for the tests. The following characteristics were determined:

(1) Uniformity of calibration factors for individual gages of the same type

(2) Variation of calibration factor with temperature

(3) Creep

(4) Effect of current on gage resistance

(5) Variation of gage resistance with temperature

This investigation was conducted at the National Bureau of Standards under the sponsorship and with the financial assistance of the National Advisory Committee for Aeronautics.

SYMBOLS

$\Delta R/R$	unit change in gage resistance R
ϵ	strain
K	calibration factor of wire strain gage
y	deflection of free end of cantilever beam, inches
ΔD	change in reading of SR-4 strain indicator
P	power, watts
E_{ac}	voltage with alternating-current source
E_{dc}	voltage with direct-current source
t	temperature, °C
α	thermal coefficient of linear expansion/°C
B	thermal coefficient of Young's modulus of elasticity/°C
l	length of cantilever beam, inches
EI	beam stiffness in bending, pound-inches^2

DESCRIPTION OF GAGES

Six types of wire strain gages, designated A to F, having gage lengths from 1/4 to 15/16 inch and resistances from 75 to 1000 ohms were included in the program. Gages of types A, B, and C were wound with advance wire and types D, E, and F were wound with isoelastic wire. Table 1 gives nominal values of gage resistance and calibration factor for each type of gage. Figure 1 shows the gages attached to test strips for calibration. The gages were attached in accordance with the manufacturer's instructions.

TESTS AND PROCEDURES

Uniformity of Calibration Factors for Individual Gages of the Same Type

Tensile calibration factors K for 10 gages of each type were computed by substituting measured values of unit change in gage resistance $\Delta R/R$ corresponding to a known change in strain $\Delta\epsilon$ in the fundamental equation:

$$K = \frac{\Delta R}{R} \frac{1}{\Delta\epsilon} \tag{1}$$

Curves of unit change in gage resistance against strain were obtained for one gage of each type prior to calibration to indicate the deviation from linearity of gage output for the first and tenth cycles of strain. All gages were subjected to a strain of 0.0021 for 10 cycles before calibration. Following the 10 prestraining cycles, the gages were calibrated by measuring $\Delta R/R$ for a tensile strain of approximately 0.0020 for gages of types A, B, and C and of 0.0010 for types D, E, and F. The calibration factor K was computed as the average value of equation (1) for five determinations on each gage.

Figure 2 shows the laboratory setup for applying known strains to the gage being calibrated. The test and compensating wire strain gages were attached to 18- by 3/4- by 1/16-inch steel bars A and B, respectively. Strains applied to the test gage during calibration were measured with Tuckerman optical strain gage C mounted on the calibration bar so as to span the wire strain gage.

The unit change in gage resistance was measured with a Wenner type ratio set in a direct-current Wheatstone bridge. The laboratory setup for resistance measurements is shown in figure 3.

Variation of Calibration Factor with Temperature

Tests were made of two gages of each type to determine the variation in calibration factor with temperature for temperatures between 30° and 160° C.

The laboratory setup for measurements of change in calibration factor with temperature is shown in figure 4. One of the calibration bars, previously used in the tensile calibrations, was shortened at one end to form a cantilever beam A (fig. 4) when clamped in frame B. The beam and frame were housed in a temperature-controlled oven. The two wire gages, attached "back-to-back" to the top and bottom faces of the beam, were connected to an SR-4 portable strain indicator (reference 1) to measure gage output resulting from bending strains in the beam. The beam was loaded at the free end with dead weights C bearing on the dial rod D. Deflections of the beam relative to the frame B were measured with a dial indicator E supported on rod F. Starting at room temperature, the beam deflection y_t and the change in the SR-4 indicator reading ΔD_t corresponding to a constant load at C were measured at different temperatures t. The load at C was chosen to produce an extreme-fiber bending strain of 10×10^{-4} underneath the strain gage.

The ratio of the average calibration factor K_t of the two gages at a temperature t to that at room temperature (30° C) is, according to equation (1),

$$\frac{K_t}{K_{30}} = \frac{(\Delta R/R)_t}{(\Delta R/R)_{30}} \frac{(\Delta \epsilon)_{30}}{(\Delta \epsilon)_t} \tag{2}$$

Since gage output $\Delta R/R$ is proportional to the change in reading of the SR-4 indicator ΔD, equation (2) can be written,

$$\frac{K_t}{K_{30}} = \frac{(\Delta D)_t}{(\Delta D)_{30}} \frac{(\Delta \epsilon)_{30}}{(\Delta \epsilon)_t} \tag{3}$$

The strain change $(\Delta \epsilon)_t$ was corrected for the increase in the moment of inertia of the beam by a factor of $(1 + \alpha\,\Delta t)^2$ because of the thermal expansion of the material corresponding to the change in temperature $\Delta t = t - 30$, and it was corrected for the change in Young's modulus with temperature by a factor of $1 + B\,\Delta t$. With these corrections equation (3) becomes

$$\frac{K_t}{K_{30}} = \frac{(\Delta D)_t}{(\Delta D)_{30}} (1 + \alpha\,\Delta t)^2 (1 + B\,\Delta t) \tag{4}$$

Equation (4) was used to compute the change in calibration factor with temperature for all gages. An average value of $\alpha = 1.2 \times 10^{-5}$ per degree centigrade was assumed for the steel beams. An average value of B was derived from measured values of the ratio y_{30}/y_t of deflections at any temperature t and 30° C. According to the cantilever-beam formula,

$$\frac{y_{30}}{y_t} = \frac{(l^3/EI)_{30}}{(l^3/EI)_t} = (1 + \alpha\,\Delta t)(1 + B\,\Delta t) \tag{5}$$

Solving equation (5) for B led to an average value

$$B = -33.5 \times 10^{-5} \text{ per degree centigrade}$$

The maximum values of the terms $(1 + \alpha\,\Delta t)^2$ and $(1 + B\,\Delta t)$ in equation (4) differed from unity by less than 0.5 percent and 6 percent, respectively. Hence, a precise determination of the thermal coefficients of expansion and of Young's modulus was not considered necessary.

Creep

Creep tests were made of two gages of type E at temperatures up to 170° C. The tests were made by observing the change in the indicated bending strain with time of two type E gages on the cantilever beam shown in figure 4 when the beam was subjected to a constant load. Tests were made for extreme-fiber strains of 5×10^{-4} and 10×10^{-4} at temperatures near 30°, 60°, 140°, and 170° C. At each temperature the change in indicated strain was observed over an interval of 1 hour following the application of load to the beam.

Effect of Current on Gage Resistance

The change in resistance with current was measured for eight gages of each type in order to estimate the allowable current for each gage. The unit change in gage resistance was measured for gages in which the test current was increased from zero in small steps over 1-minute intervals to a value at which the power dissipated by the gage was 0.5 watt for gages of types A, B, and C and 0.3 watt for gages of types C, D, and E. Measurements were made for gages attached to aluminum-alloy and steel bars.

The circuit for measuring the effect of test current on gages is shown in figure 5. It is essentially a bridge within a bridge. Four wire strain gages, r_1, r_2, r_3, and r_4, of the same type and of nominally equal resistance were connected in a balanced Wheatstone bridge called the "auxiliary" bridge. The auxiliary bridge in turn constituted the arm R of another Wheatstone bridge ABYR called the "main" bridge. The potential terminals of the auxiliary bridge were connected to an alternating-current source with adjustable voltage E_{ac}, and the potential terminals of the main bridge were connected to a direct-current source with voltage E_{dc}. Since gages r_1, r_2, r_3, and r_4 are approximately equal in resistance, very little of the alternating current in the auxiliary bridge passes through the A, B, and Y arms or through the battery and galvanometer branch of the main bridge. Therefore, the heating effect of the alternating current is confined practically to the wire strain gages in the auxiliary bridge. The unit change in resistance $\Delta R/R$ of the series-parallel arrangement $r_1r_2r_3r_4$ measured with the main bridge may then be regarded as the average change due to the alternating current flowing through the gage. The voltage E_{dc} was equal to 1.5 volts throughout these tests.

Variation in Gage Resistance with Temperature

The change in gage resistance with temperature was determined for 10 gages of each type attached to unstressed steel bars which were used originally for tensile calibrations. The temperature of the bars was varied from 30° to 160° C.

The bars were placed in the oven shown in figure 4. Each bar had two gages attached at the center in a back-to-back arrangement. One of the 10 gages was arbitrarily selected as a compensating gage. The compensating gage and each one of the remaining nine gages were connected to an SR-4 portable strain indicator. At each of several temperatures between 30° and 160° C the difference in indicated strain between each of the test gages and the compensating gage was observed. Following these measurements the actual output of the compensating gage at each temperature was determined by comparing its resistance with a fixed resistance.

RESULTS AND DISCUSSION

Calibration factors for 10 gages of each of the 6 types are given in table 2. Deviation curves, showing the departure of points on the calibration curves of one gage of each type from a straight line having a slope equal to the average factor K, are shown in figures 6 to 11 for the first and tenth strain cycles on gage 1 of each type.

Examination of the deviation curves in figures 6 to 11 shows that the hysteresis was greater on the first cycle of straining than on the tenth cycle. This may be expected on the basis of previous experience with wire strain gages (reference 2). The zero shift resulting from the hysteresis on the first cycle ranged from 0.8 percent of the applied maximum strain for the gage of type A to 3.1 percent for the gage of type C. On the tenth cycle of straining the zero shift was reduced to 0 and 0.6 percent of the applied maximum strain for types A and C, respectively. In all cases it was observed that the slopes of the deviation curves for strain decreasing from the maximum were nearly the same for the first and tenth cycles. It follows therefore that the calibration factor for decreasing strain is nearly independent of the number of cycles of strain applied and that the nonlinearity leading to hysteresis, zero shift, and varying gage factor occurs during the half of the cycle when the strain is increasing. It will be noted that the hysteresis is appreciably greater for gages of types C and F having 1/4-inch gage lengths than for types A and D having 15/16-inch gage lengths. This is ascribed to the more compact winding used in the shorter gages which presumably increases the stress carried by the cement. The increase in stress in the cement may be expected to lead to greater creep and hysteresi than for the longer gages in which the wires are widely separated and the stresses in the cement are lower. The maximum deviation of calibration factors from their average ranged from ±0.4 percent for 10 gages of type F to ±1.6 percent for 10 gages of type C.

The ratio of the calibration factor at a temperature t to the factor at room temperature (30° C) is plotted against temperature in figures 12 and 13. Examination of figures 12 and 13 shows that no significant reduction in calibration factor was observed for gages of types A and B for temperatures up to 140° C. At 170° C factors for these gages were down about 3 percent. Gages of types D and E showed a reduction in factor of about 3 percent at 140° C and about 7 percent at 170° C. Types C and F showed a reduction of about 9 percent at 140° C. The factor for type C was down 25 percent at 167° C.

Curves of creep when a constant strain ϵ was applied to the gage are shown in figure 14 for two gages of type E at temperatures of 140° C and 170° C. For applied strains of 5×10^{-4} and 10×10^{-4} negligible creep with time was observed at temperatures up to 140° C. At 170° C the creep in 1 hour amounted to about 6 percent of the applied strain.

Curves of $\Delta R/R$ against electrical power absorbed by the gage are given in figures 15 and 16 for gages attached to unstressed steel and duralumin bars. Figures 15 and 16 show that gage output varied almost linearly with the power dissipated by the gage. Power coefficients, defined as the average slope of the curve of $\Delta R/R$ against P, are given in table 3. Power coefficients were negative for gages A, B, and C which were wound with advance wire and positive for gages D, E, and F which were wound with isoelastic wire. Values of power coefficient ranged from $\Delta R/R = -10.8 \times 10^{-4}$ per watt for gage C to 190×10^{-4} per watt for gage E. In all cases the resistance of the gages increased more (or decreased less) for a given power for gages on duralumin than on steel. Since $\Delta R/R$ was found to vary almost linearly with the power dissipated, there was no obvious indication of excessive gage current. However, it appears that the power input to gages should be limited to about 0.05 watt if adequate temperature compensation is to be expected.

Curves of change in gage resistance $\Delta R/R$ against temperature for gages attached to unstressed steel bars are shown for one gage of each type in figures 17 and 18. The maximum difference in $\Delta R/R$ per degree change in temperature between any 2 of 10 gages of each type are given in table 4.

Figures 17 and 18 show that gages having advance wire grids, A, B, and C, decreased in resistance with increasing temperature and gages having isoelastic wire grids, D, E, and F, increased in resistance with increasing temperature. The temperature sensitivity of gages A, B, and C when attached to steel was found to be about $\Delta R/R = -0.14 \times 10^{-4}$ per degree centigrade for all three gage types. Gages D, E, and F each gave a temperature sensitivity near $\Delta R/R = 4.11 \times 10^{-4}$ per degree centigrade. The maximum difference in gage output with temperature for 10 gages of the same type did not exceed $\Delta R/R = 0.02 \times 10^{-4}$ per degree centigrade for the advance gages and $\Delta R/R = 0.15 \times 10^{-4}$ per degree centigrade for the isoelastic gages. In computing these data it was assumed that the thermal coefficient of expansion was the same for all test bars.

CONCLUSIONS

Tests were made on six types of bakelite-bonded wire strain gages which included representative gages utilizing advance and isoelastic strain-sensitive wires.

The calibration factors for the 10 gages of a given type that were tested differed from the average factor for that type by not more than ±1.6 percent. For one of the six types this difference was less than ±0.4 percent.

Four of the six types of gages showed a reduction in calibration factor at temperatures near 140° C which ranged from 3 to 9 percent. The decrease in calibration factor became marked for all gages as the temperature was increased to 170° C.

The changes in gage resistance due to the electric power dissipated by the gage ranged from $\Delta R/R = -10.8 \times 10^{-4}$ per watt for advance gages to 190×10^{-4} per watt for isoelastic gages. These changes correspond to maximum indicated strains of -520 microinches per watt and 5400 microinches per watt, respectively. There was no indication of damage to the gage for a power input up to 0.5 watt. However, it appears that the power input to gages should be limited to about 0.05 watt if adequate temperature compensation is to be expected.

Gages showed appreciable sensitivity to change in temperature. Fortunately, the temperature sensitivity of different gages of the same type was so nearly uniform that gages picked at random would compensate in unit change in gage resistance within 0.02×10^{-4} per degree centigrade for the gages using advance wire and within 0.15×10^{-4} per degree centigrade for the gages using isoelastic wire.

National Bureau of Standards
Washington, D.C., May 5, 1947

REFERENCES

1. Anon.: SR-4 Portable Strain Indicator. Bull. 169, Baldwin Southwark Div., Baldwin Locomotive Works (Philadelphia), 1942.

2. Campbell, William R.: Performance Tests of Wire Strain Gages. I - Calibration Factors in Tension. NACA TN No. 954, 1944.

TABLE 1.- DESCRIPTION OF GAGES

Gage type	Gage length (in.)	Nominal resistance (ohms)	Calibration factor, K (approx.)	Strain-sensitive wire
AB-1 A	15/16	350	2.04	Advance
AB-5 B	1/2	75	2.02	
AB-7 C	1/4	120	1.96	
CB-1 D	15/16	1000	3.53	Isoelastic
CB-5 E	1/2	200	3.48	
CB-7 F	1/4	500	3.30	

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TABLE 2.- RESULTS OF TENSILE CALIBRATIONS

Gage type	Gage number	Calibration factor, K	Average K
A	1	2.084	
	2	2.083	
	3	2.097	
	4	2.093	
	5	2.094	
	6	2.087	
	7	2.094	
	8	2.100	
	9	2.110	
	10	2.077	2.092
B	1	2.082	
	2	2.053	
	3	2.092	
	4	2.046	
	5	2.064	
	6	2.085	
	7	2.048	
	8	2.063	
	9	2.091	
	10	2.072	2.065
C	1	2.032	
	2	2.003	
	3	1.999	
	4	2.010	
	5	1.981	
	6	1.997	
	7	2.040	
	8	2.013	
	9	2.025	
	10	2.017	2.012
D	1	3.358	
	2	3.331	
	3	3.316	
	4	3.354	
	5	3.337	
	6	3.338	
	7	3.353	
	8	3.356	
	9	3.298	
	10	3.369	3.341
E	1	3.273	
	2	3.250	
	3	3.286	
	4	3.288	
	5	3.234	
	6	3.300	
	7	3.238	
	8	3.272	
	9	3.262	
	10	3.215	3.262
F	1	3.226	
	2	3.238	
	3	3.231	
	4	3.218	
	5	3.226	
	6	3.218	
	7	3.238	
	8	3.233	
	9	3.216	
	10	3.222	3.227

TABLE 3.- POWER COEFFICIENTS[1]

Gage type	Power coefficient ($(\Delta R/R)$/watt) of gage	
	On steel	On duralumin
A	-3.3×10^{-4}	-0.3×10^{-4}
B	-10.4	-6.2
C	-10.8	-6.5
D	73	142
E	166	190
F	142	188

[1]Power coefficient, $(\Delta R/R)(1/P)$; that is, the unit change in gage resistance per watt of power dissipated by the gage.

TABLE 4.- TEMPERATURE SENSITIVITIES OF GAGES

ATTACHED TO UNSTRESSED STEEL BARS

Gage type	Temperature sensitivity ($(\Delta R/R)/^{\circ}C$)	Maximum difference in $(\Delta R/R)/^{\circ}C$ between any 2 of 10 gages
A	-0.14×10^{-4}	0.008×10^{-4}
B	-.14	.020
C	-.15	.015
D	4.11	.127
E	4.11	.150
F	4.11	.088

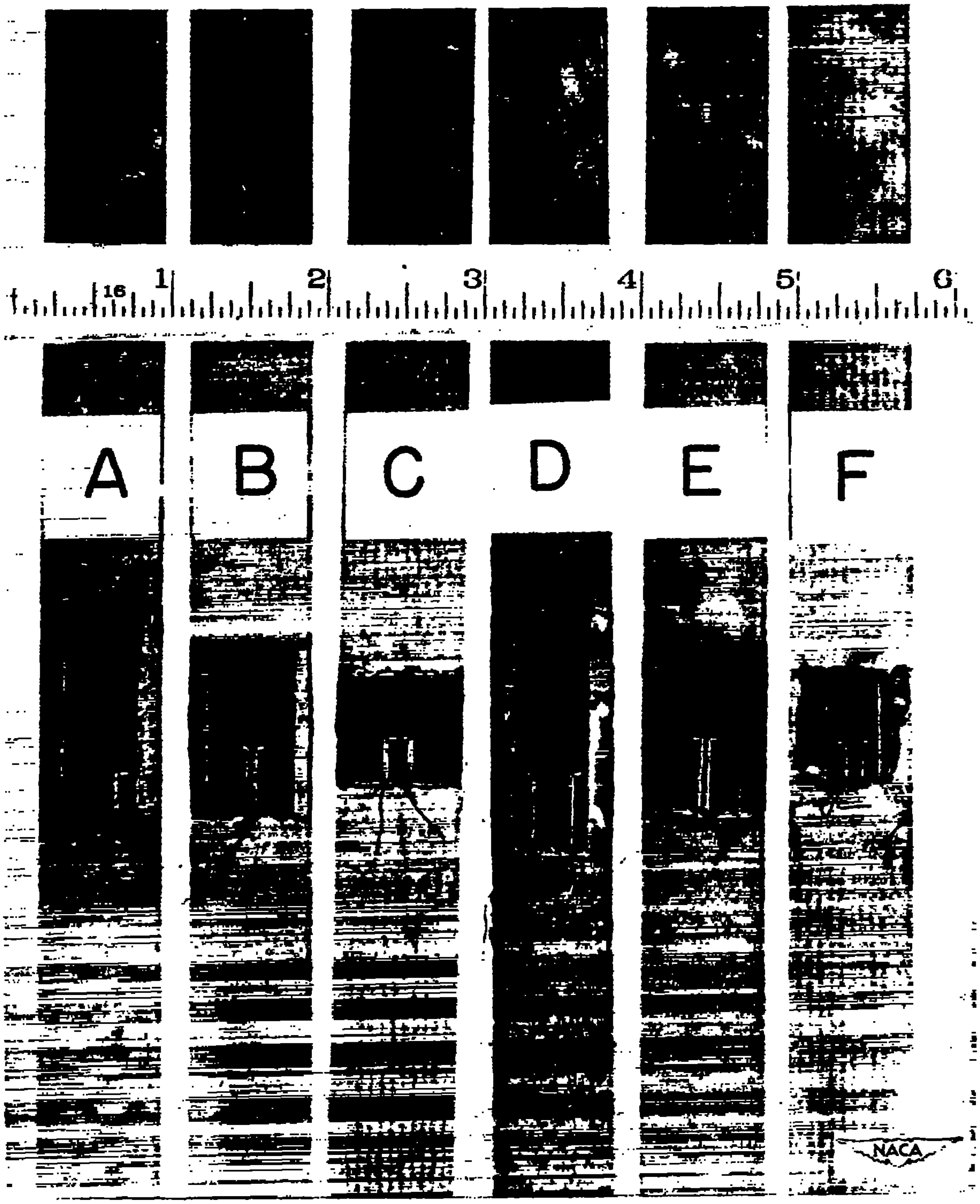

Figure 1.- Gages attached to test strips for calibration.

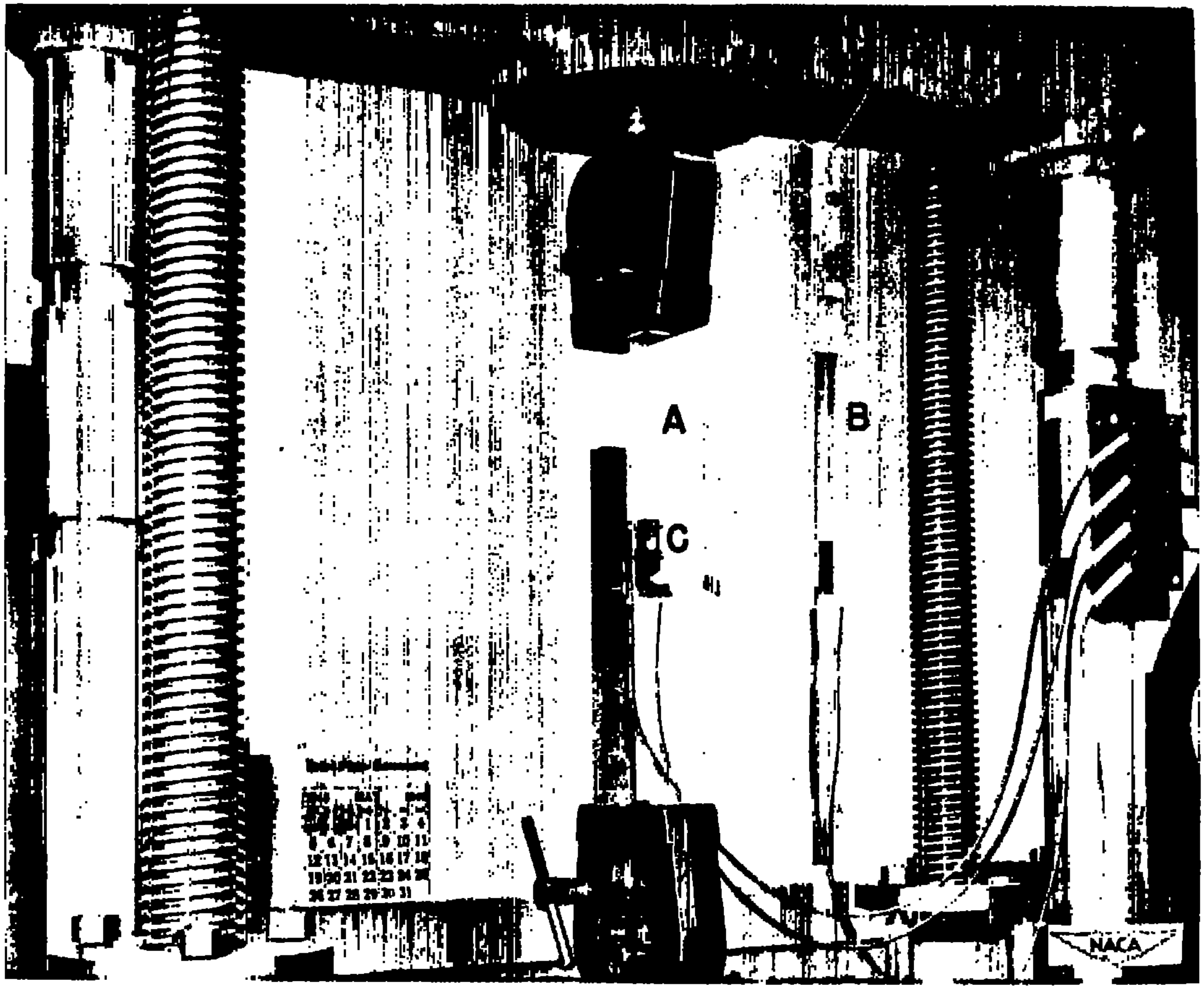

Figure 2.- Setup for applying known strains to gage being calibrated.

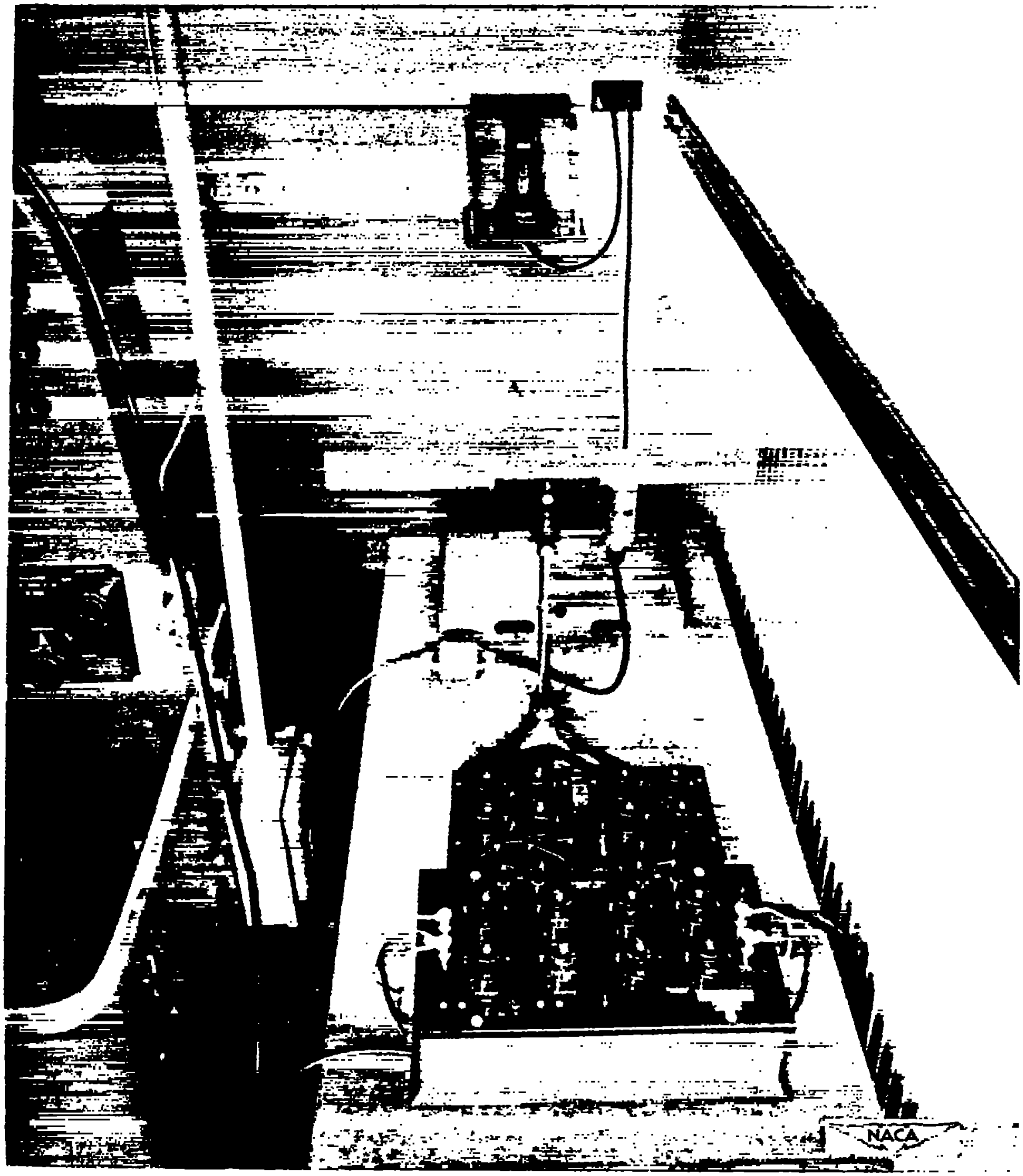

Figure 3.- Setup for measuring gage resistance.

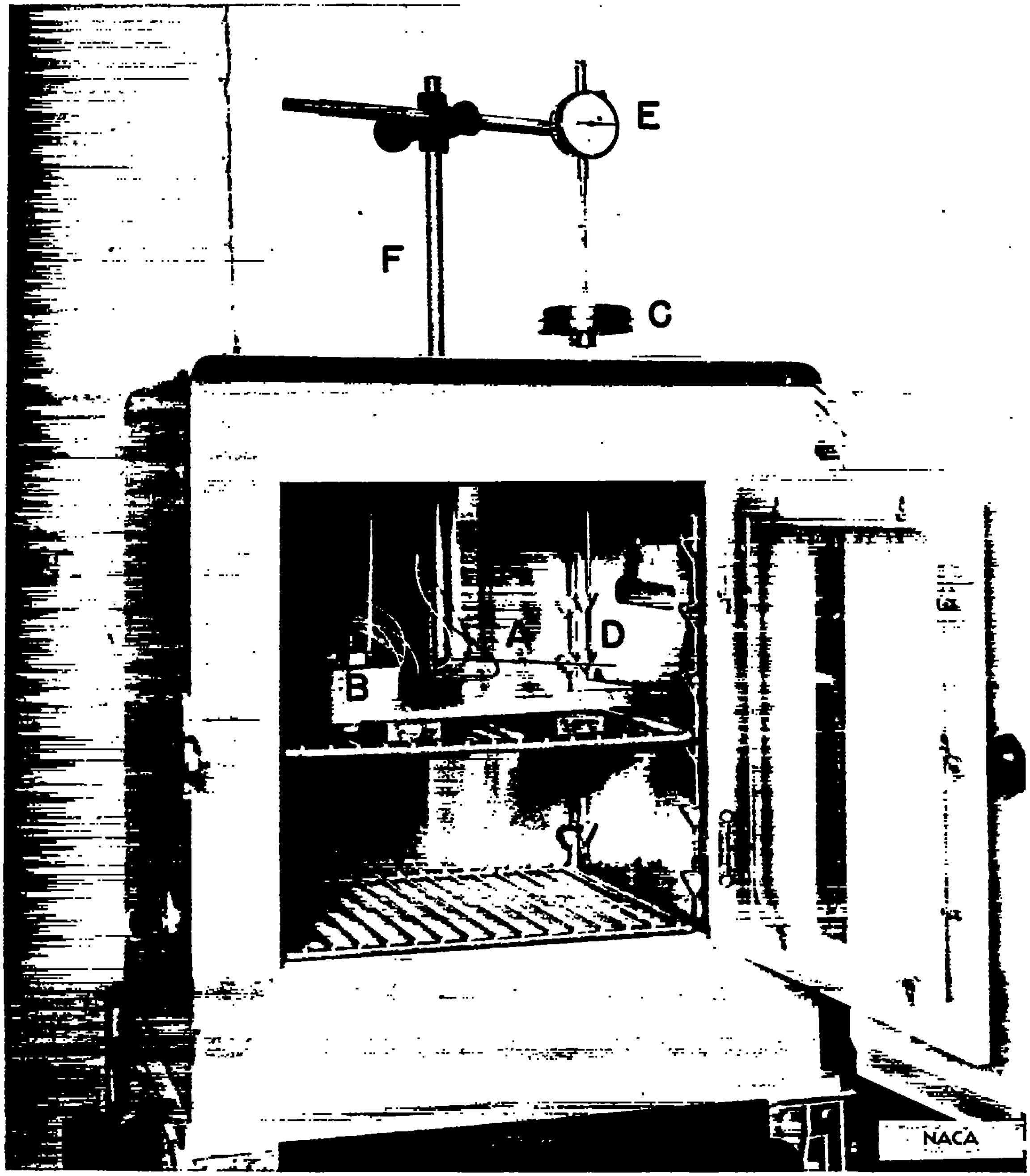

Figure 4.- Setup for measuring change in calibration factor with temperature.

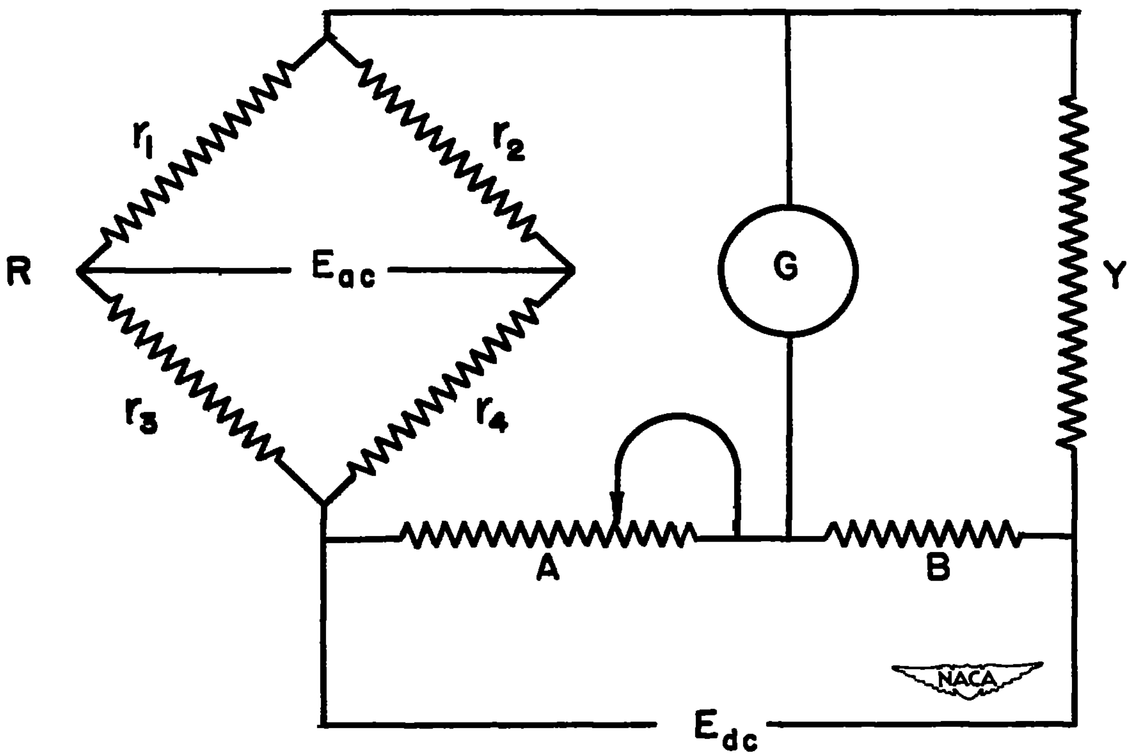

Figure 5.— Circuit for measuring effect of test current on gages.

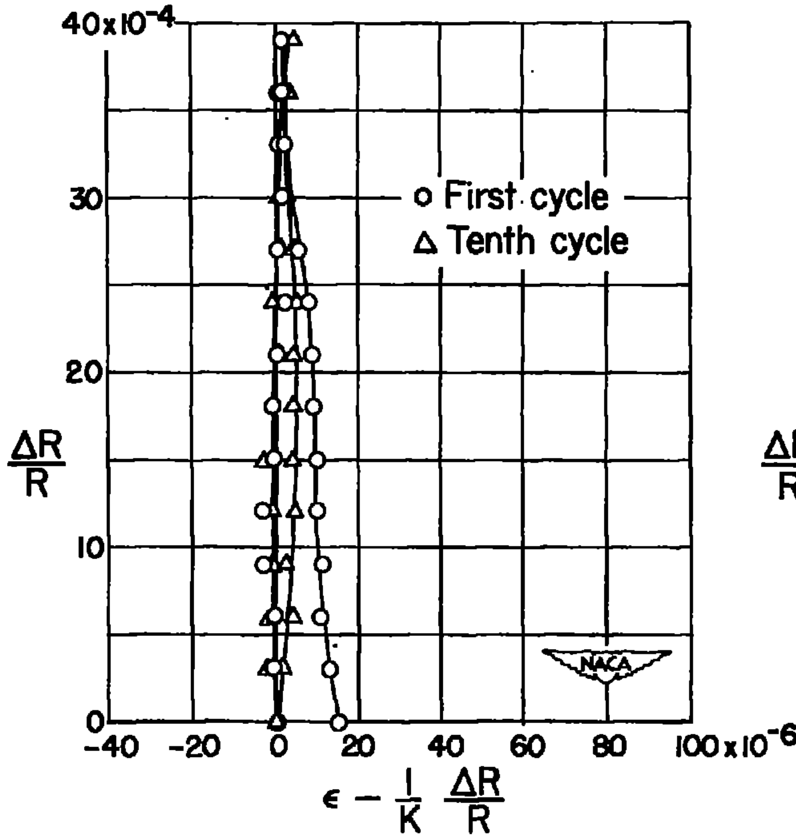

Figure 6.- Deviation curves for gage 1 of type A.

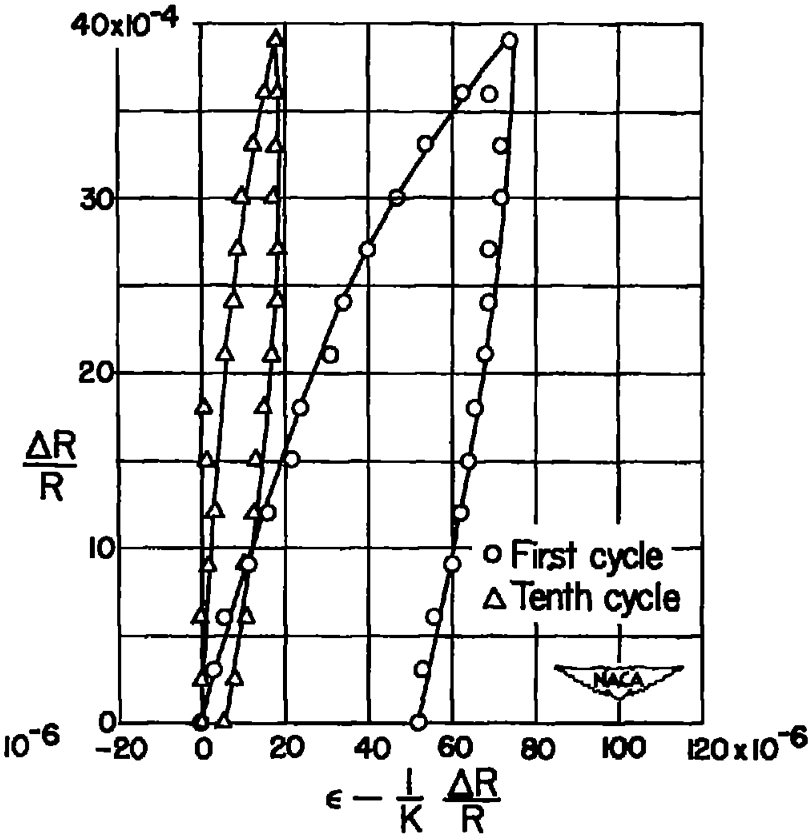

Figure 7.- Deviation curves for gage 1 of type B.

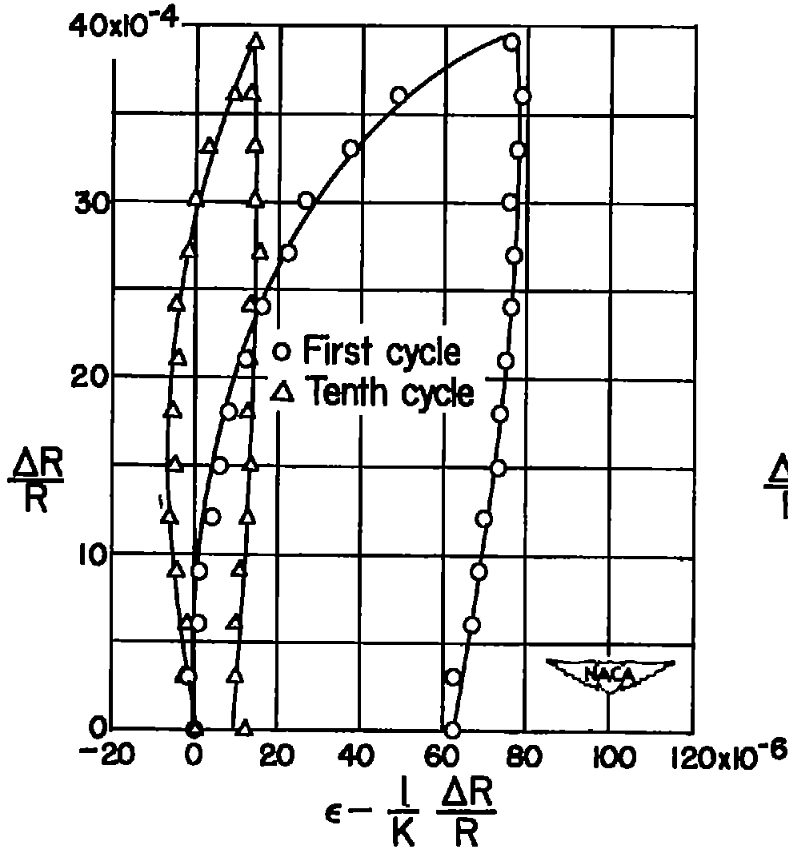

Figure 8.- Deviation curves for gage 1 of type C.

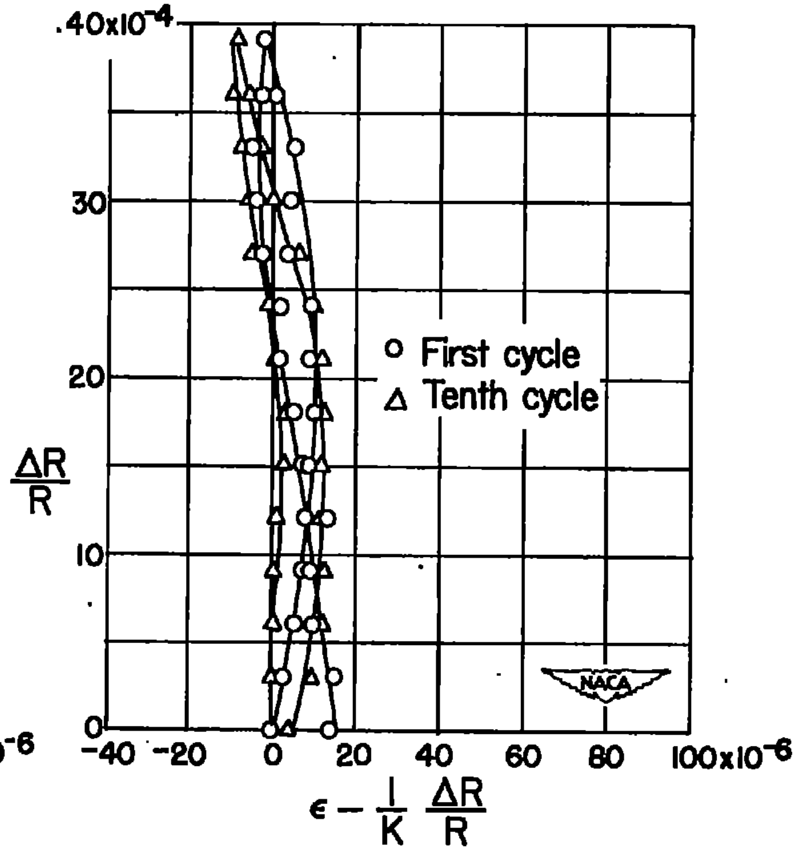

Figure 9.- Deviation curves for gage 1 of type D.

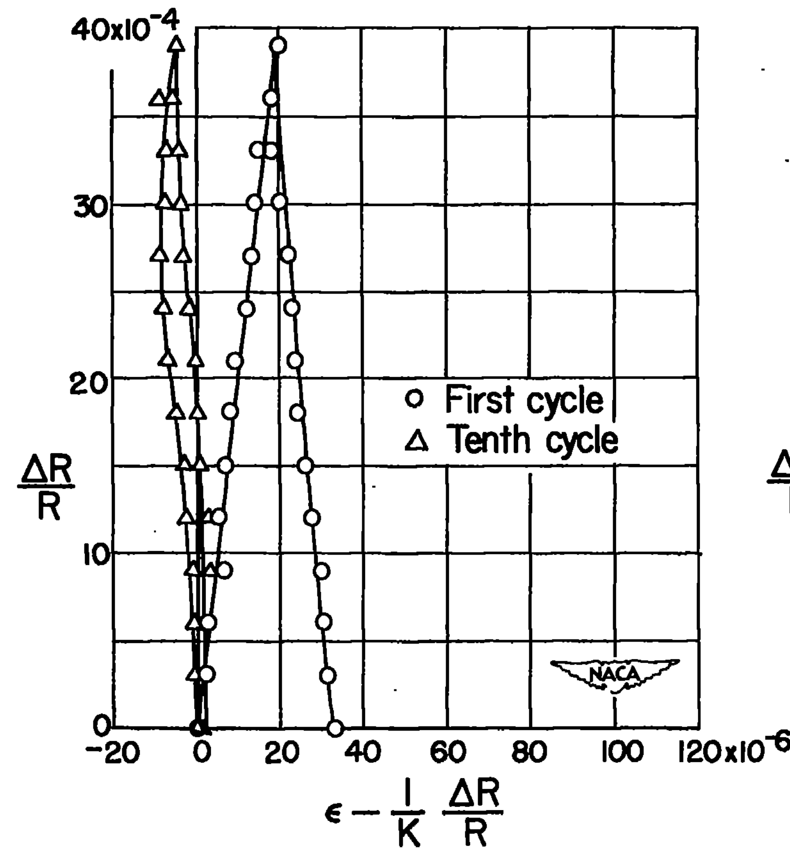

Figure 10.- Deviation curves for gage 1 of type E.

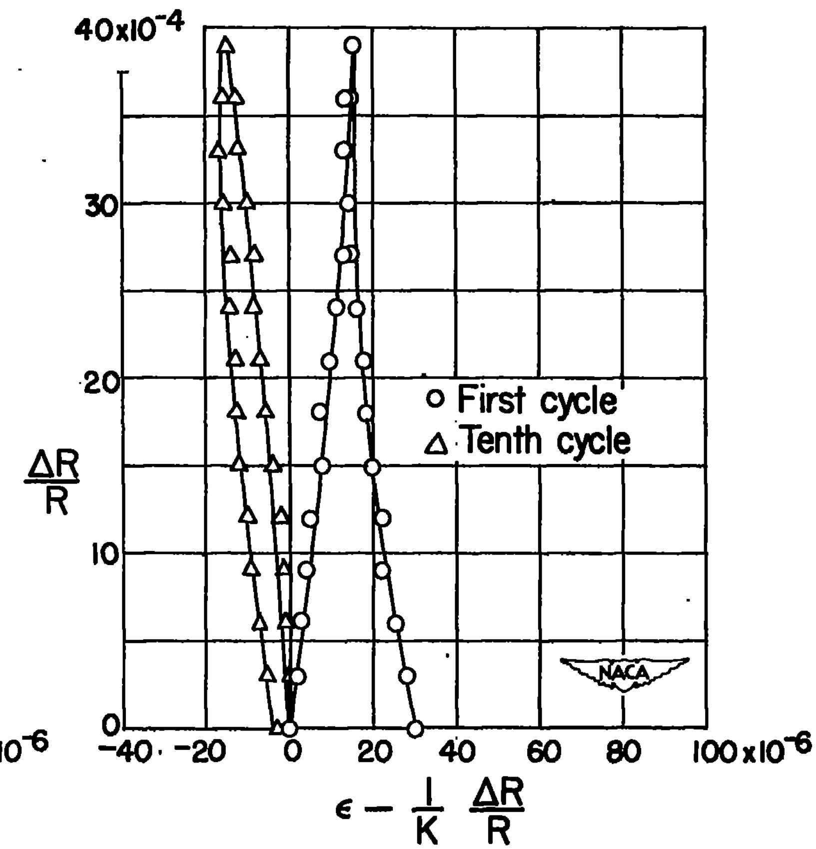

Figure 11.- Deviation curves for gage 1 of type F.

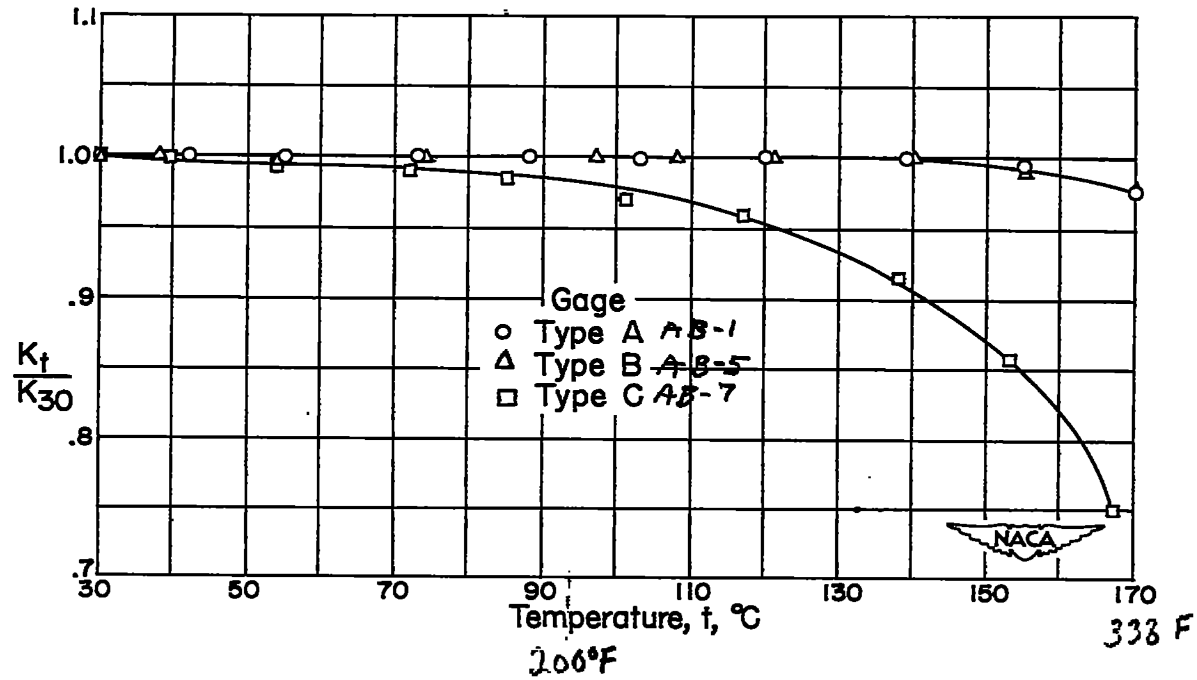

Figure 12.- Curves of ratio of calibration factors K_t/K_{30} against temperature t for gages of types A, B, and C.

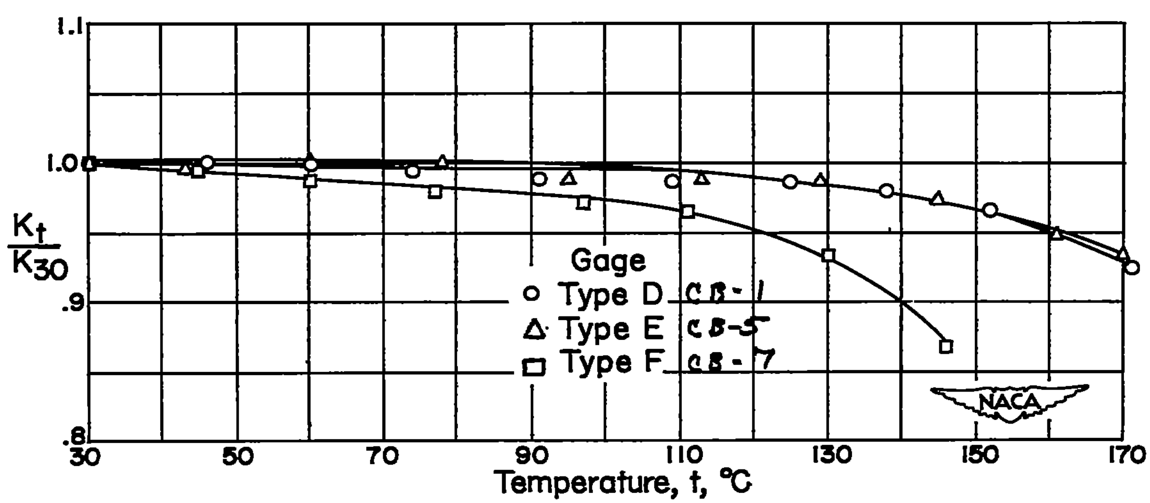

Figure 13.- Curves of ratio of calibration factors K_t/K_{30} against temperature t for gages of types D, E, and F.

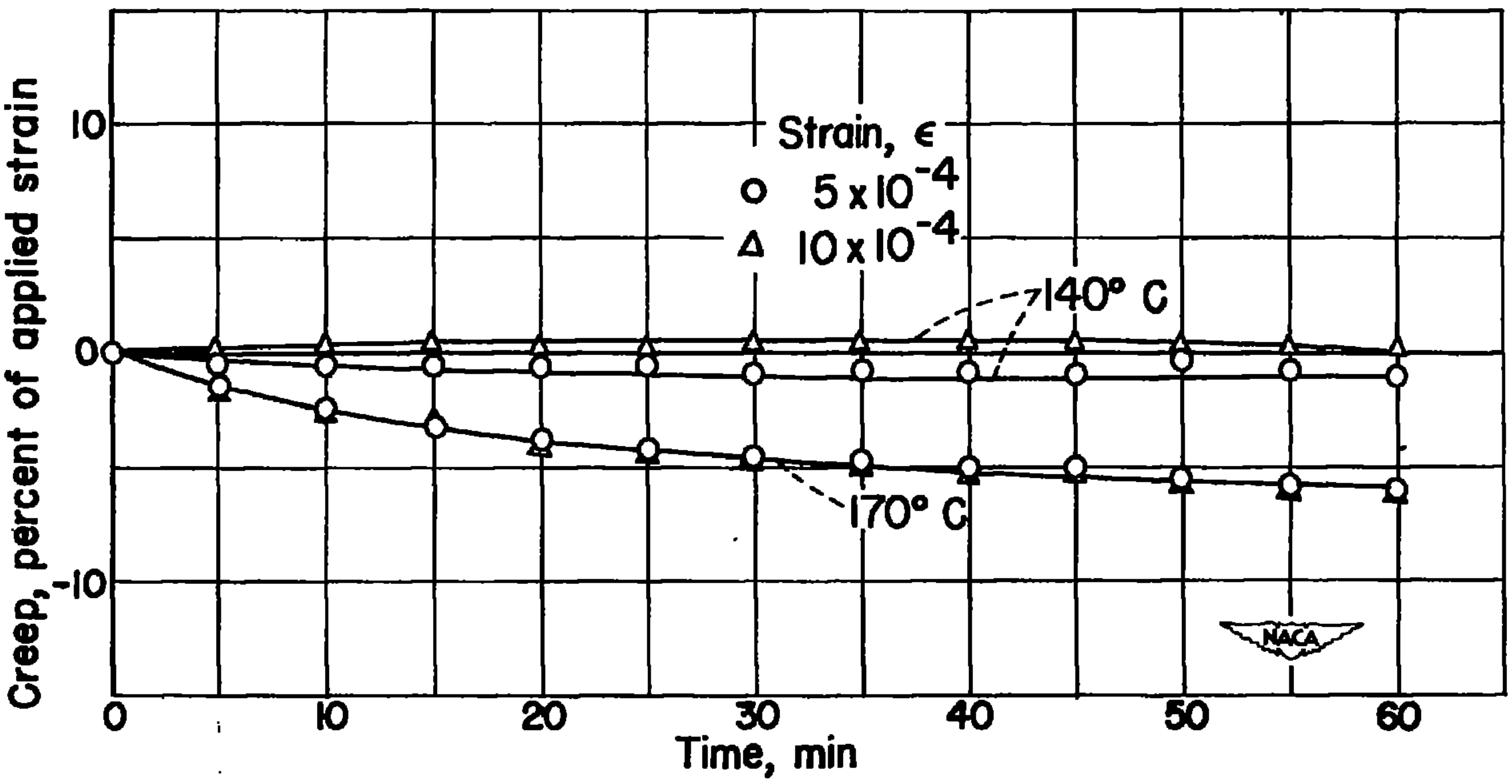

Figure 14.- Curves of creep with a constant strain ϵ applied to two gages of type E at two temperatures.

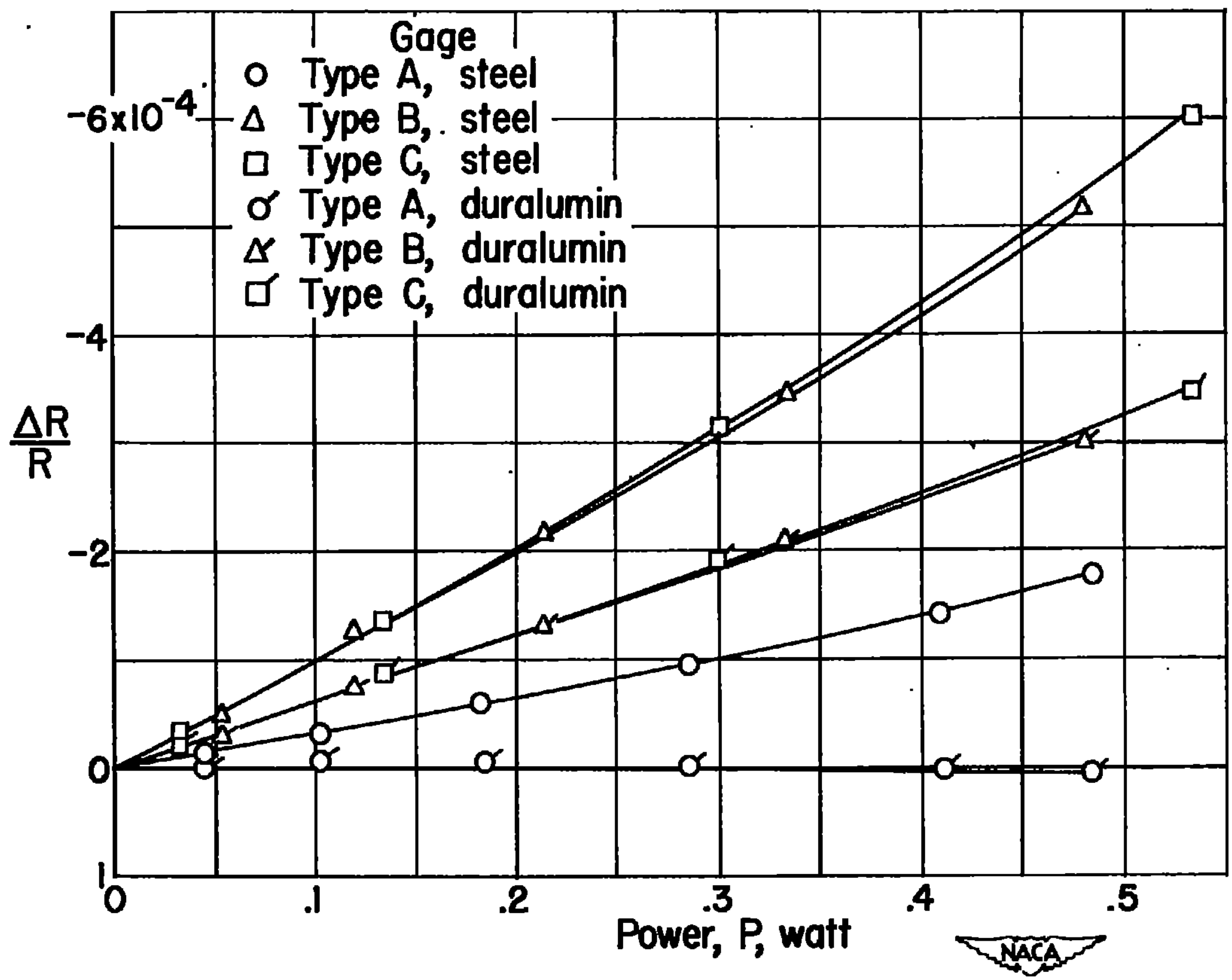

Figure 15.- Curves of change in gage resistance $\Delta R/R$ against electrical power absorbed P for gages of types A, B, and C attached to unstressed steel and duralumin bars.

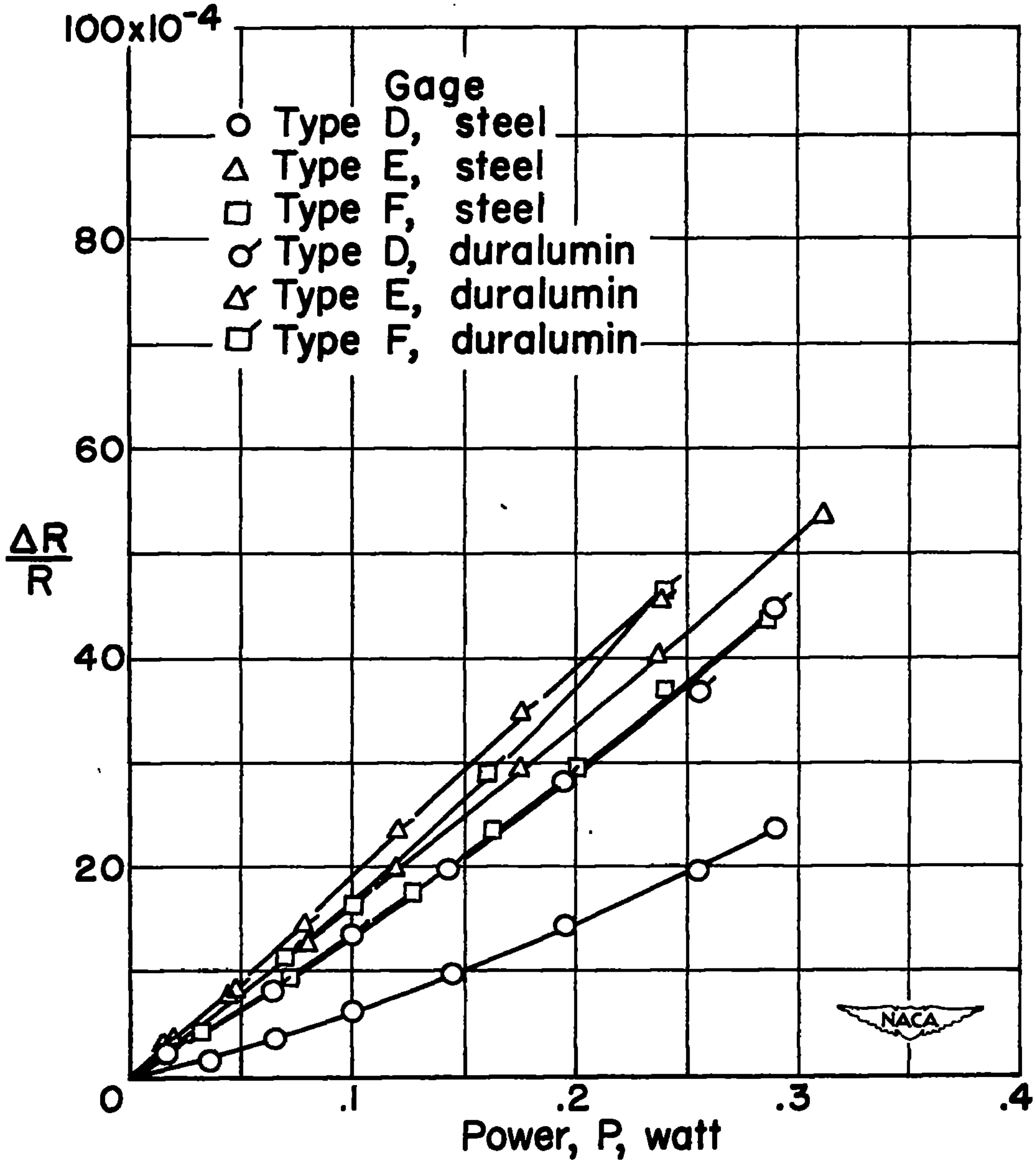

Figure 16.- Curves of change in gage resistance $\Delta R/R$ against electrical power absorbed P for gages of types D, E, and F attached to unstressed steel and duralumin bars.

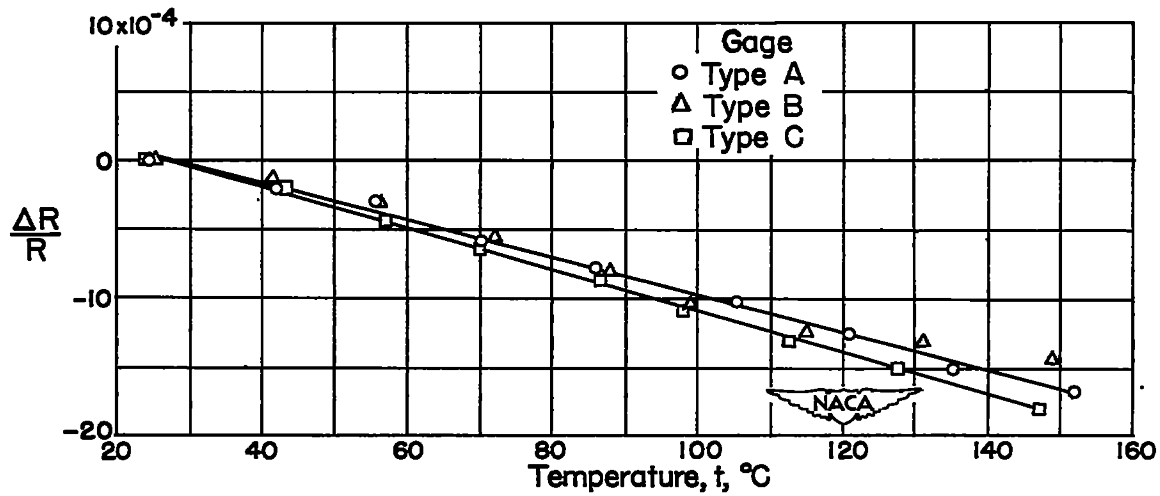

Figure 17.- Curves of change in gage resistance $\Delta R/R$ against temperature t for one gage of each of types A, B, and C attached to unstressed steel bars.

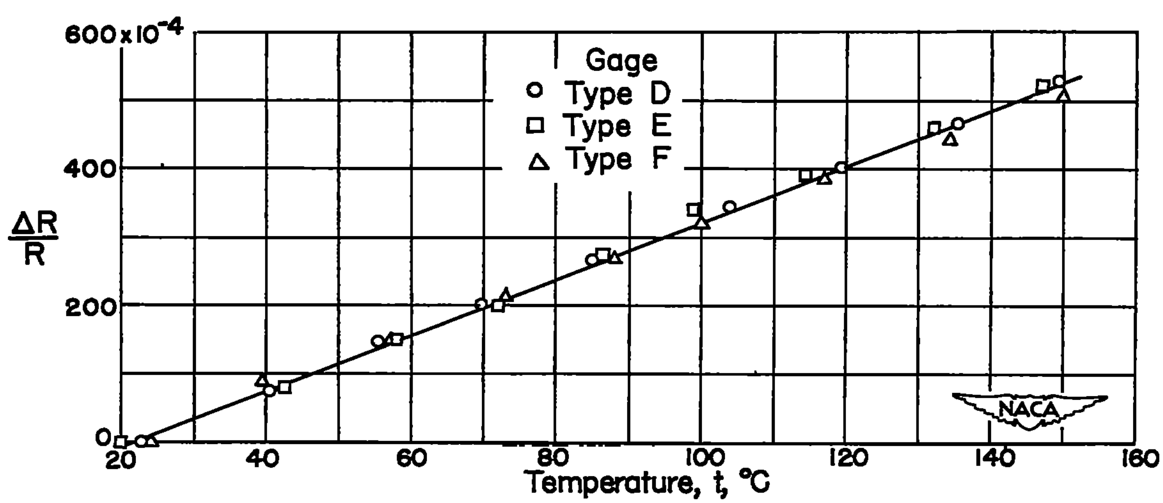

Figure 18.- Curves of change in gage resistance $\Delta R/R$ against temperature t for one gage of each of types D, E, and F attached to unstressed steel bars.